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© O. Barauskiene, PhD, Associate Professor, S. Zyhulia, PhD, Associate Professor, Igor Sikorsky Kyiv Polytechnic Institute, Kyiv Ukraine

OPTIMAL CONTROL OF THE COMPLEX PROCESS OF MANUFACTURING CYLINDRICAL PARTS' PRINTING EQUIPMENT

Algorithm of complex technological process was developed for the calculation of geometric parameters in the case of partial-regular microrelief formation after vibration run-in and chrome plating. Also determine the complex of processing methods that deliver the quality of the set of surface layer in order to increase the operational properties of the parts of printing equipment.

Keywords: strengthens finishing-processing; oscillation rolling; regular microrelief; chromium plating parameters; microrelief formation algorithm; printing machines.

Introduction

Improvement of quality and performance properties of machines, mechanisms and processing equipment is an urgent issue of modern mechanical engineering. The reason is that significant material, economic and social resources are used for the production, repair and maintenance of machinery, spare parts of machines and mechanisms. Modern machines are characterized by a continuous increase in capacity and workloads along with the increase of speed and acceleration of their actuators, transfer of increasing and torque moments, resulting in significant increase of requirements for the reliability of the machines. The fail of service performance and the accelerated failure during operation usually are the result of processes that take place on the surface layers of parts, namely friction, wear and tear, redistribution of residual stresses and their excessive concentration, the formation of micro cracks and strength degradation [1].

A significant place in solving these problems is given to the development of new technological processes for the manufacture of parts along with improving the design of machines and equipment and rational choice of materials for their parts in order to ensure the necessary performance properties of the material from which they are made.

Evaluation of criteria of the quality of parts of friction units of printing equipment is not only about dimensional accuracy and roughness of the executive surfaces, but also about physico-chemical properties of the surface layer of the material of the part: composition and properties of friction films (so-called secondary structures), microgeometry relief, which overwhelmingly have priority importance in ensuring the reliability and durability of the part.

Consequently, the main targets of technology at the present stage along with continuous improvement of processes that ensure the accuracy of size and shape of parts also is the creation of new and improvement of existing manufacturing technologies to provide the surface layer of material details with required functional properties [2].

One of the important directions of increasing the operational properties of the parts of printing equipment and consequently improving the reliability of printing equipment is to obtain the specified properties of the surfaces of the parts by methods of surface hardening. Topical from the point of view of increasing the operational properties is the combination of galvanic and chemical methods of coating with the simultaneous formation of regular microreliefs on the surface by methods finishing-strengthening treatment. Due to its high corrosion resistance and wear resistance, chromium coating is already used as a protective agent in many industries.

When solving the problems of technological quality assurance of the parts' surface and operational properties it is necessary to provide the quality parameters of the suface layer of machine parts according to their purpose in order to predict the processing modes and determine the complex of processing methods that deliver the quality of the set of surface layer parameters with the highest productivity.

Analysis of previous studies

In order to increase durability, reduce the energy losses due to friction and reduce noise during of operating equipment during the process design, special attention is paid to the selection of finishing processing operations. It is desirable that a microrelief of the appropriate form is formed on the surface and the necessary degree of surface strengthening is formed [3].

Depending on the working conditions of the parts, it is necessary to provide the necessary type of microrelief, which would satisfy the aforementioned requirements. Actually the problem arises during attempts of simultaneous achieving of significant hardening of the surface and increasing of roughness parameters, which further increases the surface quality parameters and the unit operational properties of printing equipment, affecting the quality of manufactured products.

One of the known methods is the method of finishing-strengthening processing [4], in which, in order to increase productivity and broaden the technological capabilities of the tool, they force-rotate at an angular speed which calculated in accordance with certain dependence. The disadvantage of this method is that a completely regular microrelief is formed on the part's surface by surface-plastic deformation, resulting in sagging that increases the surface roughness. In places where irregularities intersect, surface delamination may occur as well as a puncture.

If we consider the processing on cylindrical surfaces, which is performed in two transitions [5], while on the first transition on the

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surface a partially regular microrelief of a sinusoidal type of concave shape is performed by an indenter with a tip radius R = 0.5–4 mm when feeding S = 0.7–4.0 mm/rev and the speed of rotation of the part n_3 = 100–400 rev/mm, then at the second transition the force of pressing is reduced by 50–75 %, the flow — to S = 0.02–0.1 mm/rev and the number of rotations of the part n_3 = 50–200 rev/mm, while leaving the number of oscillations unchanged and form a completely regular microrelief of the tetragonal or hexagonal type on the surface in the areas that were not processed during the first transition, thus changing due to the repeated transition of the deforming element, the parameters of partially regular microrelief. The disadvantage of this approach is that the specified method of increasing the hardness of the surface layer is in the range of 10–15 %. Formation of a completely regular micro-relief on the surface of tetragonal or hexagonal type is characteristic of surfaces that work in contact with other surfaces; it is used with the aim of increasing the hydro-density; the formation on surface of two types of microrelief, reduces the wear resistance, compared to surface geometry, on which only partially-regular microrelief is formed, due to the presence of a completely regular micro-relief.

The article [6] examines the study physical and mechanical properties of printing cylinders after the application of a completely regular microrelief with subsequent chrome plating which allows to obtain a surface with less roughness and greater hardness. However, the article does not consider a general integrated approach to algorithmization this method of processing.

Purpose of research

Justification of implementation of complex technology on cylindrical surfaces of the corresponding details of printing equipment with the view to improve the quality parameters of the surface and surface layer, as well as operational properties.

Research results

The basis of the proposed complex technological process is set to improve the quality of the surface and surface layer, as well as operational properties by forming of a partially regular microrelief of a sinusoidal type on the cylindrical surfaces, in which there is no intersection of irregularities, with subsequent application of chromium layers on these surfaces, that change according to the size of the deposited layer.

To form a regular microrelief on a cylindrical workpiece we have proposed a complex technological process that involves rotating a cylindrical workpiece at a constant speed around its axis and forming partially regular microrelief in two stages. During the first stage a partial-regular microrelief perform, on the surface of the part with regular irregularities of sinusoidal type, which do not intersect with the following modes of processing: radius of the sphere of the deforming tool R = 1.0–3.0 mm, with a force of indentation P = 50–500 H, eccentricity tool deformation e = = 0.4–1.5 mm, spindle speed n_{sp} = = 20–800 rpm, oscillation frequency ndouble step = 1250–2500 1/min and feed rate S = 0.15–3 mm/rev, at the second stage, the metal surface is chromed. The scheme of microrelief formation is shown in fig. 1.

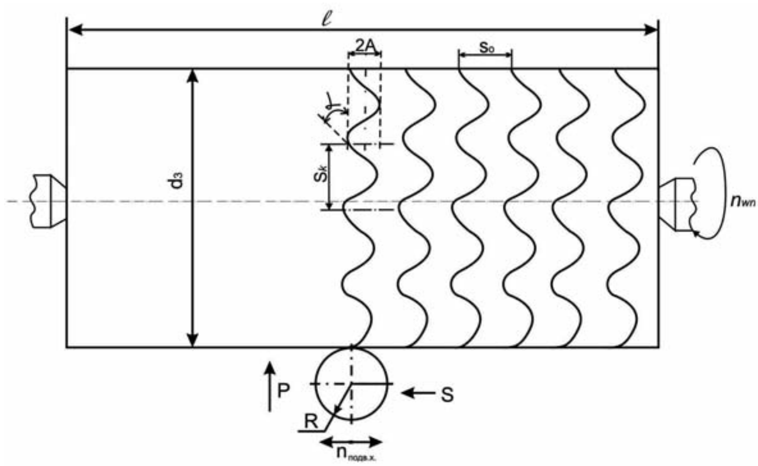

Fig. 1. Surface microrelief obtained after surface-plastic deformation treatment, where A — the amplitude of a continuous regular irregularity, S_k — the angular step of irregularities, S_o — the axial step of irregularities, α is the angle of the grid

The parameters of microrelief after application of semi-regular microrelief are within the limits, namely the width of the micro-irregularities b = 0.15–0.6 mm, the height of the micro-irregularities h = 0.0003–0.009 mm, the height of the inflows h_H = 0.0002–0.0048 mm, and after chromium plating — b_1 = 0.148–0.58 mm, h_1 = 0.0001–0.0048 mm, h_{H1} = 0.0002–0.0052 mm (fig. 2).

The automatic control system adds new features to printing equipment, making it possible to execute a large number of high-quality orders in short time.

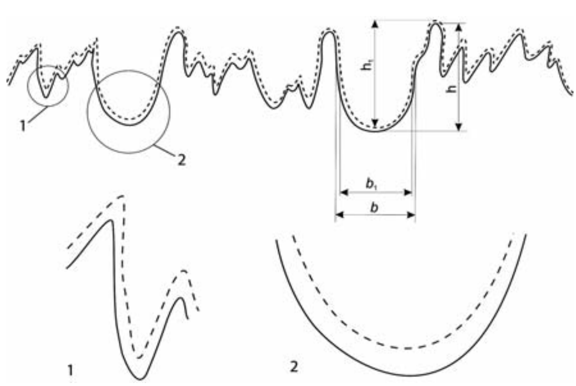

Fig. 2. Surface microrelief obtained after vibration run-in and subsequent chromium plating, where b — micro-roughness width after vibration-rolling, b_1 — micro-roughness width after complex technology, h — micro-roughness depth, which includes the flow height, after vibration-rolling, h_1 — micro-roughness depth, which includes flow height, following complex technology

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Automatic control can significantly increase the speed of working modes of printing equipment. The speeds of the operating modes are increasing so much that the operator is not able to keep track of their course due to physiological limitations. Due to the high speeds of the operating modes, the execution time of each specific order is reduced.

More important than increasing the speed of operating modes is a significant reduction in the time of preparatory work in highly automated equipment because automatic control saves materials and electricity [7].

For purposeful control of technological processes, an algorithm of complex technological process was developed on the basis of the analysis of the specified technological scheme for the calculation of geometric parameters in the case of partial-regular microrelief formation after vibration run-in and chrome plating (fig. 3).

According to it, the first step of the algorithm (fig. 3) is the entering of input data such as workpiece diameter (d_3), mm, workpiece length (L), mm, arithmetic mean deviation of profile (R_a), µm, workpiece material and hardness (by Brinell, HB or Vickers hardness, HV, or Rockwell hardness, HRC). Then we select the shape, size, pattern of the microrelief in the cell 'Choosing the shape and type of microrelief'. We choose the shape of the microrelief, concave or convex; we also choose the type of micro-relief: chess or annular arrangement of irregularities, no intersection of regular irregularities, incomplete intersection of regular irregularities or complete intersection of regular irregularities. The choice of cell 'Selection of material of the deforming element and the geometry of the deforming tool' gives the opportunity to choose a steel hardened ball, diamond tip or carbide tip; in this cell we also choose the radius of the deforming tool (R), mm, which can usually be from 0.5 to 4 mm.

We select the force value from 50 to 1000 H in the cell 'Selection of the force of pressing of the deforming tool, P'. In the cell 'Selection of equipment' it is necessary to select the equipment for conducting vibration rolling' we will refer to the type of such metal-cutting machines as lathes in terms of this equipment. When choosing a lathe, we determine the feed of the deforming tool (S), mm/rev, select the number of spindles n_{sp}, rpm, which are available to this machine according to the specifications of the machine passport, then choose the processing scheme, namely for one pass, for two or three passes. Depending on the device by which the vibration run-in will be performed, we choose the number of oscillations ($n_{double\ step}$), double steps per minutes, and also determine the ratio $i = \frac{n_{double\ step.}}{n_{шп}}$, that will allow to determine the relative location of the irregularities. This algorithm is designed for the mutual arrangement of irregularities (there is no intersection of regular irregularities).

When the condition is fulfilled, we proceed to the next step — choosing the eccentricity of the tool deforming (e), mm, and determine the amplitude of irregularity (A), which is equal to 2e, mm. According to State Standard 24773-81 'Surfaces with regular microrelief.

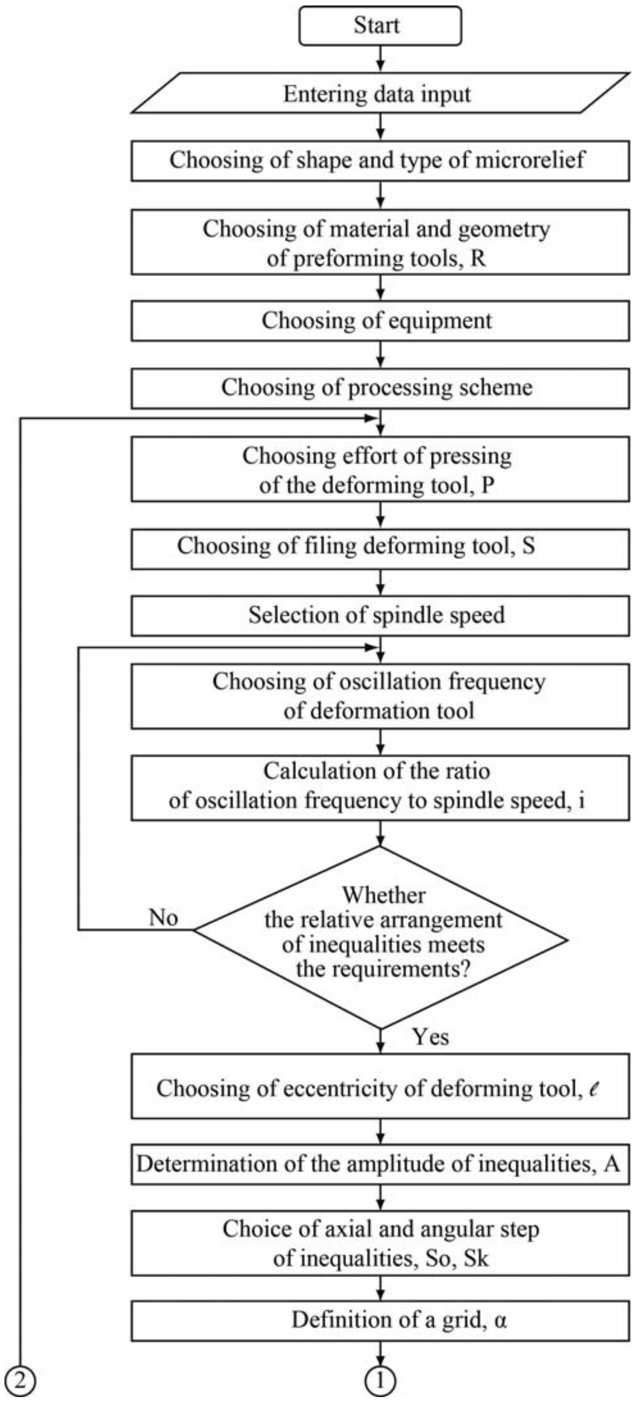

Fig. 3. The algorithm of complex technological process of microrelief formation on the surfaces of details of printing equipment. Beginning

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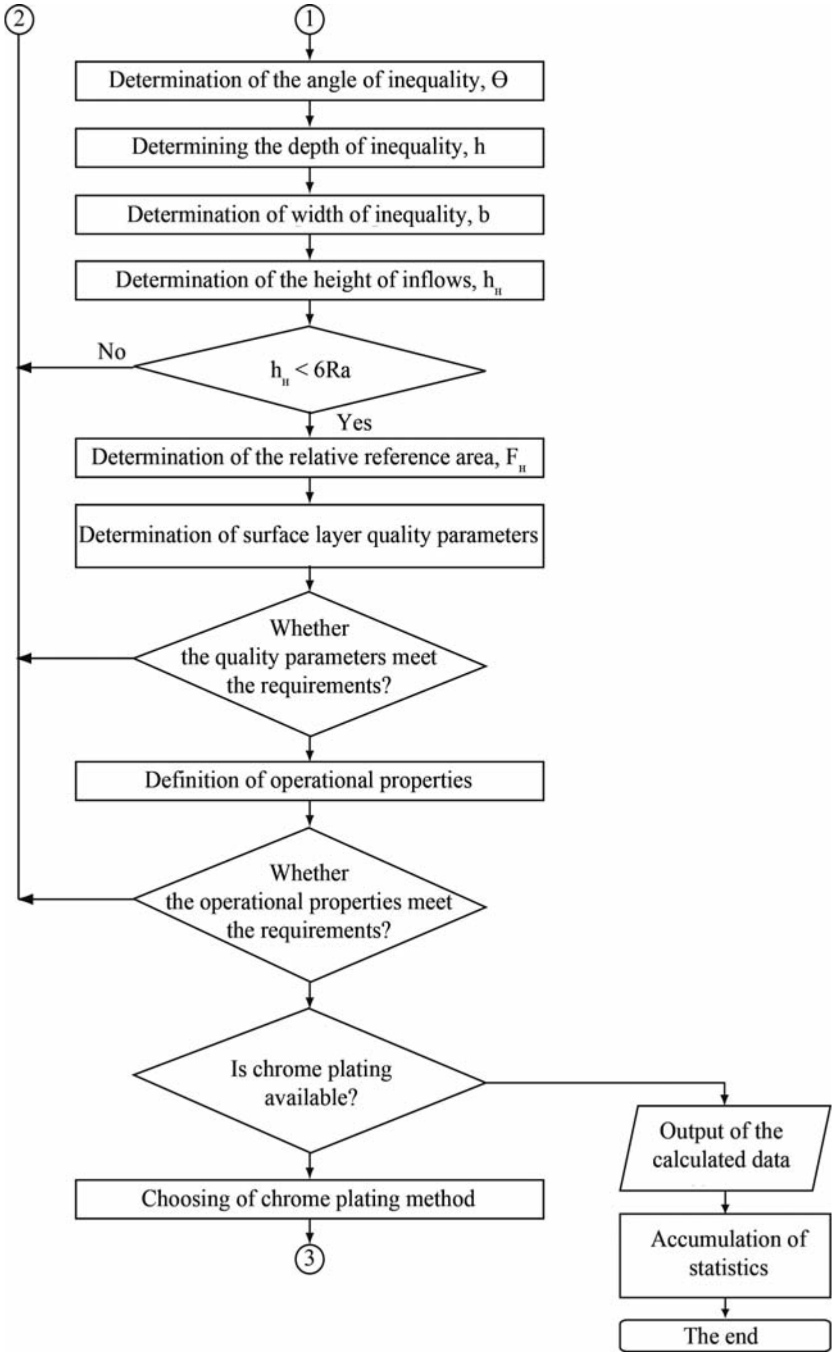

Fig. 3. The algorithm of complex technological process of microrelief formation on the surfaces of details of printing equipment. Continuation

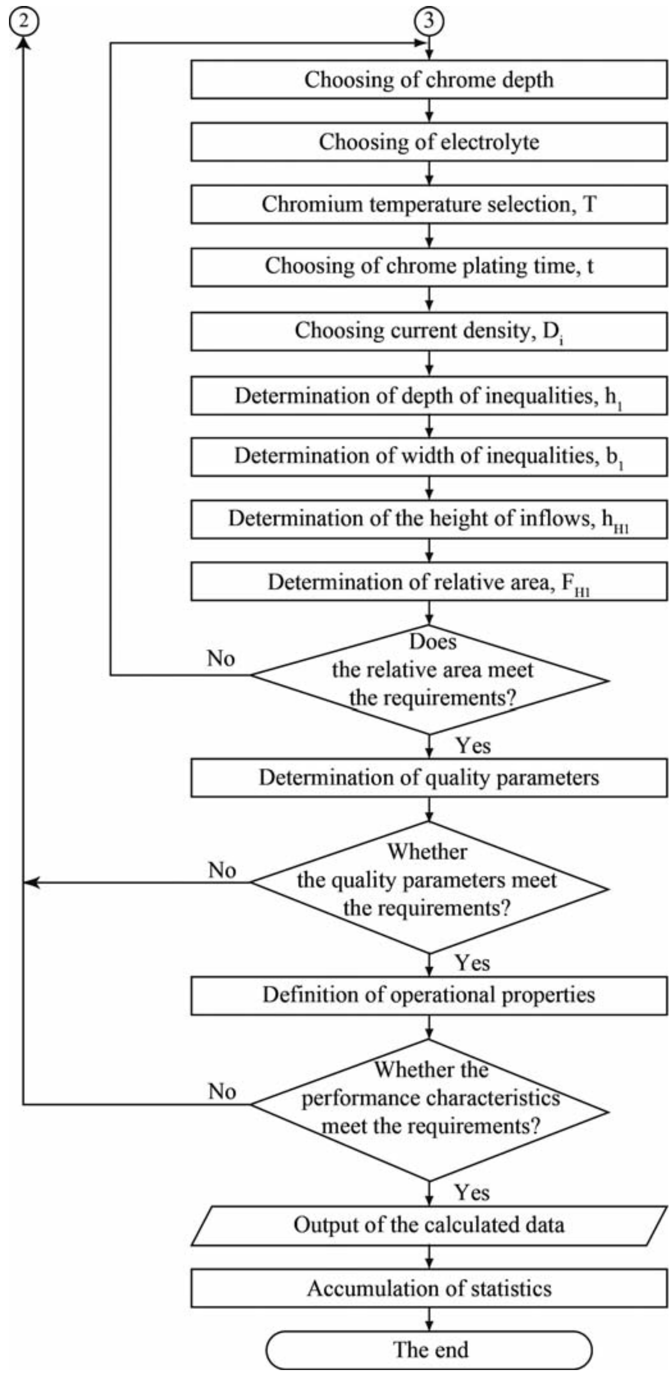

Fig. 3. The algorithm of complex technological process of microrelief formation on the surfaces of details of printing equipment. End

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Classification, parameters and characteristics' choose the angle of irregularity (Θ), which can be in the range 0, 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 80, 85, 90 degrees. The axial step of irregularities (S_o) and the angular step of irregularities (S_k), mm can be 20; 16; 12.5; 10; 8; 6,3; 5; 4; 3,2; 2.5; 2; 1.6; 1.25; 1; 0.8; 0.63; 0.5; 0.4; 0.32; 0.25; 0.1; 0.08; 0.063; 0.05.

Determine the angle of the grid (α) according to [8]:

$$\alpha = \operatorname{arctg}\frac{2ei}{d_з},$$

where e — is the eccentricity of the tool, mm; d_3 — diameter of the workpiece, mm.

After that, the depth (h) and width (b) of regular irregularities, mm, as well as the flow heights $h_н$, μm are calculated.

To determine the depth of irregularities we use the formula [9]:

$$h = \frac{P}{\pi \cdot R \cdot HV},$$

where P — impressing force, H; HV — Vickers material hardness, H/mm^2; R — radius of the tool deformation, mm.

We also determine the width of the irregularity by the formula [10]:

$$b = 2\sqrt{h(2R - h)}.$$

Inflow height $h_н$, μm calculated approximately by the empirical formula designed by V. S. Ivanenko [11]:

$$h_н = 217{,}41\frac{P}{HB \cdot d_з}.$$

But the height of the influx $h_н$ should not exceed $6R_a$.

Then, when the condition is satisfied, we determine the relative area ($F_н$), % by the following analytical dependence:

$$F_н = \frac{4\rho n_{шп}}{\pi v_1}\sqrt{1 + \left(2i\frac{A}{d_з}\right)^2} \cdot$$

$$\cdot E\left(\frac{2Ai}{d_з^2 + (2Ai)^2}\right)100 \quad , \%.$$

where $\rho = \sqrt{R \cdot h}$ — the radius of the thickness of the print, mm; R — radius of tool deformation, mm; h — height (depth) of irregularity after application of semi-regular microrelief, mm; n_{sp} — spindle speed, rpm; v_1 — translational speed of deformation movement, mm/min; i — ratio of magnitude of double strokes of the deforming tool $n_{double\ step}$, to the spindle speed

$n_{sp}\left(i = \frac{n_{подв.х.}}{n_{шп}}\right)$; ndouble step — oscillation frequency of the instrument, double steps per minutes; A — amplitude of continuous regular irregularity, mm; d_3 — workpiece diameter, mm; E — a complete normal elliptic Legendre 2nd-order integral:

$$E(k) = \frac{\pi}{2}\sum_{n=0}^{\infty}\left(\frac{(2n)!}{2^{2n} \cdot (n!)^2}\right) \cdot$$

$$\cdot \frac{k^{2n}}{1 - 2n}.$$

Using statistics, you can determine the quality parameters of the surface layer and performance. If the data meets the requirements, we proceed to the next step.

Since after the finishing-strengthening treatment, namely the vibration coating, the next operation is chrome plating, it is necessary to determine the method of chrome plating. Determining with the method of chromium plating and the thickness of the chromium layer, we choose the chromium modes, which include temperature, ^oC, chromium time (holding time), h, current density, A/dm^2, as well as the electrolyte, which, for example, may consist of CrO_3, g/l, or %, H_2SO_4, g/l, or %. Depending on the method of chromium plating, the modes of chromium plating and the electrolyte, we obtain respectively the depth (h1), the width (b1) of regular irregularity, and the height of inflows (h_{H1}) in mm and calculate the relative area occupied by regular irregularities (F_{H1}) according to the following analytical dependence:

$$F_{H1} = \sqrt{1 + \left(2i\frac{A}{d_з}\right)^2} - -2h_1 \frac{\left(2i\frac{A}{d_з}\right)^2 \frac{1}{d_з}}{\sqrt{1 + \left(2i\frac{A}{d_з}\right)^2}} 100,\ \%,$$

where h_1 — height (depth) of irregularity after chrome plating, mm.

The geometric parameters of microrelief after complex technology are determined by the mathematical dependencies obtained during the experimental studies.

Next, the following blocks are used to determine the quality parameters and check the set parameters. After that, the determination of the operational properties and their verification, if obtained operational properties do not meet the appropriate requirements, we perform the block of corrections of the mathematical model according to the accumulated statistics [3, 12–14].

Analytical dependences F_H and F_{H1} between the relative area, occupied by regular irregularities of the sinusoidal type, allow to form the necessary value of the relative area on the surface under operating conditions, allowing to reproduce the amount necessary to increase the durability on the cylindrical surfaces and also to provide corresponding oil-binding capacity [15].

Increasing the oil-binding capacity and resistance to tear of the chrome coating can be achieved by applying microrelief in the form of holes and grooves to the chrome plating. The wear resistance and chrome setting are affected by the parameters of the oil-binding microrelief of the surface. Wear of the chrome coating, deposited at temperature of 58–66 degrees, decreases at boundary friction up to 15–20 % with the increase of porosity due to the grooves. If porosity increases by more than 30–35 %, the wear of chromium increases drastically. This nature of the dependence indicates that increase of the relative area to the corresponding value improves oil-binding capacity without noticeable weakening of the coating.

Considering the speed of operation of chrome-coated parts, it is desirable to recommend a complex technology with a relative area of 25–35 % and microhardness of 8500–11500 MPa, which allows obtaining of sufficiently high durability [16].

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Conclusions

The proposed process and the partial results of the experiments indicate the high efficiency of the complex technological process.

Application of proposed algorithm allows taking into account a large number of conditions that affect the surface quality and performance, determining the geometric parameters of the microrelief, reducing the risk of errors in the selection and performing comparative analysis of quality of the surface layer and performance properties on the totality of their characteristics.

The influence of technological factors on surface area with partially regular microrelief is determined, the limits and conditions of practical variation of values of the relative surface area are determined in order to increase the operational properties of details of printing equipment.

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Розроблено алгоритм комплексного технологічного процесу для розрахунку геометричних параметрів при нанесені часткового регулярного мікрорельєфу після вібраційного обкатування і хромування. А також визначено комплекс методів обробки, що забезпе-

чують отримання заданих параметрів якості поверхневого шару для підвищення експлуатаційних характеристик поліграфічного обладнання.

Ключові слова: оздоблювально-зміцнювальна обробка; вібраційне накатування; регулярний мікрорельєф; параметри хромування; алгоритм формування мікрорельєфу; поліграфічні машини.

Рецензент — Ю. Ю. Віцюк, канд. техн. наук, доц., КПІ ім. Ігоря Сікорського

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